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In re Application of :

Masahiro TOTSUKA et al. :

Serial No. 10/784,947 : Group Art Unit: 2822

Filed: May 9, 2003 : Examiner: AU, BACH

For: SURFACE STABILIZING METHOD AND METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE

VERIFICATION OF ENGLISH TRANSLATION

Assistant Commissioner
for Patents
Washington, D.C. 20231

Sir:

I, Haruo NAKANO , declare that I am conversant in both the Japanese and English languages and that the English translation as attached hereto is an accurate translation of Japanese Patent Application No. 2003-131263 filed on May 9, 2003.

Signed this 1st day of November, 2005

PATENT OFFICE
JAPANESE GOVERNMENT

This is to certify that the annexed is a true copy of the following application as filed with this Office.

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Application Number : Patent Application No. 2003-131263

Applicant(s) : Mitsubishi Denki Kabushiki Kaisha

November 11, 2003

Commissioner,
Patent Office

Yasuo IMAI (seal)

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Title of the Invention: Surface Stabilizing Method and Method of Manufacturing Semiconductor Device

Number of Claims: 8

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Item:	Specification	1 copy
Item:	Drawings	1 copy
Item:	Abstract	1 copy

Request for Proof Transmission: Yes

[DOCUMENT NAME] SPECIFICATION

[TITLE OF THE INVENTION] SURFACE STABILIZING METHOD AND METHOD OF MANUFACTURING SEMICONDUCTOR DEVICE

[SCOPE OF THE CLAIMED INVENTION]

[Claim 1] A surface stabilizing method of stabilizing a surface of a gallium nitride related semiconductor substrate, using a catalytic chemical vapor reaction apparatus, comprising:

a step of arranging a gallium nitride related semiconductor substrate inside a catalytic chemical vapor reaction apparatus;

a step of introducing nitrogen-containing gas into said catalytic chemical vapor reaction apparatus;

a decomposition step of decomposing said nitrogen-containing gas by means of a catalytic reaction and forming atom-state nitrogen; and

a step of contacting said atom-state nitrogen with said semiconductor substrate and nitriding a surface of said semiconductor substrate.

[Claim 2] The surface stabilizing method of claim 1, wherein said decomposition step is a step at which said nitrogen-containing gas is brought into contact with a heated catalyst member and decomposed.

[Claim 3] A method of manufacturing a semiconductor device using a gallium nitride related semiconductor,

comprising:

a step of preparing a substrate whose surface is formed by a gallium nitride related semiconductor;

a nitriding step of contacting said surface with atom-state nitrogen which is obtained by decomposing nitrogen-containing gas by means of a catalytic reaction, to thereby nitride said surface; and

an electrode forming step of forming, on said surface, a gate electrode and a source and a drain electrodes which are arranged opposing said gate electrode.

[Claim 4] The manufacturing method of claim 3, wherein said nitriding step is a step at which said surface is selectively nitrided, and

said electrode forming step is a step at which said electrodes are formed on said surface thus selectively nitrided.

[Claim 5] A method of manufacturing a semiconductor device using a gallium nitride related semiconductor, comprising:

a step of preparing a substrate whose surface is formed by a gallium nitride related semiconductor;

a step of forming, on said surface, a gate electrode and a source and a drain electrodes which are arranged opposing said gate electrode; and

a nitriding step of contacting said surface, at an

area between said source electrode and said gate electrode and at an area between said drain electrode and said gate electrode, with atom-state nitrogen which is obtained by decomposing nitrogen-containing gas by means of a catalytic reaction, to thereby nitride said surface.

[Claim 6] The manufacturing method of any one of claims 3 through 5, wherein said nitriding step is a step at which an aluminum layer is formed in said surface and a surface of said aluminum layer is nitrided.

[Claim 7] A method of manufacturing a semiconductor device using a gallium nitride related semiconductor, comprising:

a step of preparing a substrate whose surface is formed by a gallium nitride related semiconductor;

a step of forming, on said surface, a gate electrode and a source and a drain electrodes which are arranged opposing said gate electrode;

a step of forming an insulation or aluminum film so as to cover the entire surface; and

a nitriding step of contacting said surface, at an area between said source electrode and said gate electrode and at an area between said drain electrode and said gate electrode, with atom-state nitrogen which is obtained by decomposing nitrogen-containing gas by means of a catalytic reaction, to thereby nitride said surface.

[Claim 8] The manufacturing method of claim 7, wherein said nitriding step is a step at which said atom-state nitrogen transmitted by said insulation or aluminum film is brought into contact with said surface and said surface is thereby nitrided.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[TECHNICAL FIELD OF THE INVENTION]

The present invention relates to a surface stabilizing method for gallium nitride related semiconductor and a method of manufacturing a semiconductor device using the same, and more particularly, to a method which uses a catalytic chemical vapor reaction apparatus.

[0002]

[PRIOR ART]

With a field effective transistor in which a gallium nitride (GaN) related semiconductor is used as the material of a substrate, one cannot obtain excellent DC and high-frequency characteristics. This is due to a trap which is present at a surface of the substrate, and hence, it is necessary to stabilize the surface. According to a conventional approach, a substrate is irradiated with plasma of N_2, NH_3 or the like, voids created by nitrogen atoms, oxygen atoms and the like existing on a surface of the gallium nitride substrate are substituted with nitrogen

atoms (which is nitriding), and the surface is stabilized (See Patent Document 1 for instance.).

[0003]

[Patent Document 1]

JP, 06-244409, A

[0004]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

However, irradiation of plasma upon a surface of a substrate would inevitably result in plasma-induced damage, which would adversely affect electric characteristics and the like of a semiconductor device fabricated using such a substrate.

[0005]

Noting this, the present invention aims at providing a surface stabilizing method which permits to stabilize a surface without damaging the surface.

[0006]

[MEANS TO SOLVE THE PROBLEM]

The present invention is directed to a surface stabilizing method of stabilizing a surface of a gallium nitride related semiconductor substrate, using a catalytic chemical vapor reaction apparatus, including: a step of arranging a gallium nitride related semiconductor substrate inside a catalytic chemical vapor reaction apparatus; a step of introducing nitrogen-containing gas into the

catalytic chemical vapor reaction apparatus; a decomposition step of decomposing the nitrogen-containing gas by means of a catalytic reaction and forming atom-state nitrogen; and a step of contacting the atom-state nitrogen with the semiconductor substrate and nitriding a surface of the semiconductor substrate.

Use of this surface stabilizing method makes it possible to nitride and stabilize a surface while preventing damage upon the surface which would be caused by irradiated plasma according to a conventional technique.

[0007]

[PREFERRED EMBODIMENTS OF THE INVENTION]

Fig. 1 is a schematic drawing which shows the inside of a catalytic chemical vapor reaction apparatus which is generally denoted at 50 and used according to this embodiment.

The catalytic chemical vapor reaction apparatus 50 includes a substrate stage 1 inside a chamber (not shown). On the substrate stage 1, there is a wafer 2 whose surface is to be stabilized. In addition, a gas introduction portion 3 is disposed inside the chamber in such a manner that the gas introduction portion 3 is approximately opposed against the substrate stage 1. The gas introduction portion 3 has a plurality of holes for instance, thereby allowing supply of reactive gas 4 through

these holes.

[0008]

Disposed in the vicinity of the gas introduction portion 3 is a heat catalyst member 5 formed by a tungsten wire for instance. A distance between the substrate stage 1 and the heat catalyst member 5 is from about 20 mm to about 100 mm.

A shutter 6 is disposed between the substrate stage 1 and the heat catalyst member 5. When the shutter 6 opens, surface stabilizing treatment of the wafer 2 is initiated, and when the shutter 6 closes, surface stabilizing treatment of the wafer 2 is finished.

[0009]

Surface stabilizing treatment of a gallium nitride substrate will now be described with reference to Fig. 1.

First, the wafer 2 formed by a gallium nitride related semiconductor is placed on the substrate stage 1 as described above. The substrate stage 1 includes a heater and holds the wafer 2 at a temperature of 100℃ for example.

[0010]

Next, the reactive gas 4 containing N_2, NH_3 or the like for instance is introduced from the gas introduction portion 3. When NH_3 is used, the rate of gas flow is 100 sccm and the degree of vacuum is 10 Pa, for example. Further, the surface temperature of the heat catalyst

member 5 of tungsten for instance is 1500℃.

[0011]

Through a catalytic reaction caused by the heat catalyst member 5, the reactive gas 4 supplied from the gas introduction portion 3 is decomposed into atom-state nitrogen.

[0012]

These conditions are set with the shutter 6 closed, and after the conditions have been stabilized, the shutter 6 opens. With the shutter 6 open, atom-state nitrogen is supplied upon the surface of the wafer 2, whereby the surface is nitrided, i.e., stabilized. To terminate the surface stabilization, the supply of the reactive gas 4 or the like is stopped after closing the shutter 6.

[0013]

In this manner, atom-state nitrogen is supplied upon the surface of the wafer 2 which is formed by a gallium nitride related semiconductor, nitrogen-induced voids, oxygen atoms (natural oxygen film) and the like existing at the surface of the wafer 2 are substituted with nitrogen atoms, thus achieving surface stabilization of the wafer 2.

[0014]

Although this embodiment requires to nitride and accordingly stabilize the surface of the wafer 2 which is formed by a gallium nitride related semiconductor, an Al

layer may be formed in advance on the surface of the wafer 2 which is formed by a gallium nitride related semiconductor and the aluminum layer may then be nitrided to form an AlN layer for surface stabilization.

According to this method, the Al layer is deposited on the surface of the wafer 2 before loading the wafer 2 into the catalytic chemical vapor reaction apparatus 50. The film thickness of the Al layer is from about 10 angstroms to about 50 angstroms, and preferably, about 20 angstroms.

[0015]

Further, gallium nitride related semiconductors include, in addition to those of GaN, those of AlGaN and the like which are obtained by substituting Ga and/or N of GaN with other atoms.

[0016]

[Examples]

The following examples are applications of the surface stabilizing method according to the preferred embodiment described above to manufacturing of a semiconductor device. While the following will be directed to a field effective transistor, the surface stabilizing method may be applied to other semiconductor devices such as HEMT.

[0017]

Example 1

Fig. 2 is a cross sectional view which shows steps of

manufacturing a field effective transistor according to the example 1 which is generally denoted at 100. These manufacturing steps include the following steps 1 through 4.

[0018]

Step 1: As shown in Fig. 2(a), first, on a substrate 11 of SiC or sapphire, a substrate 10 seating a GaN epitaxial layer 12 is prepared.

[0019]

Step 2: As shown in Fig. 2(b), using the catalytic chemical vapor reaction apparatus 50 described above, a surface of the epitaxial layer 12 is nitrided, thereby forming a GaN surface-nitrided layer (stabilized layer) 20.

[0020]

Step 3: As shown in Fig. 2(c), on the GaN surface-nitrided layer 20, a gate electrode 14, and a source electrode 15 and a drain electrode 16 opposing the gate electrode are formed.

[0021]

Step 4: As shown in Fig. 2(d), a passivation film 17 of silicon nitride for instance is formed so as to cover the gate electrode 15 and the like. At this step, the field effective transistor 100 is completed.

[0022]

In the field effective transistor 100, the interface between the gate electrode 14, the source electrode 15 and

the drain electrode 16 and the interface between the passivation film 16 and the GaN epitaxial layer 12 are stabilized.

[0023]

While the example 1 requires to directly nitride the surface of the GaN epitaxial layer 12, an aluminum layer may be vapor-deposited on the GaN epitaxial layer 12 and then nitrided to thereby stabilize the surface as that of an aluminum nitride layer. This is similar in the following examples 2 through 5.

[0024]

Example 2

Fig. 3 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 2 which is generally denoted at 200. In Fig. 3, the same reference symbols as those used in Fig. 2 denote the same or corresponding portions. These manufacturing steps include the following steps 1 through 3.

[0025]

Step 1: As shown in Fig. 3(a), first, on the substrate 11 of SiC or sapphire, the substrate 10 seating the GaN epitaxial layer 12 is prepared. Following this, the gate electrode 14, the source electrode 15 and the drain electrode 16 are formed on the epitaxial layer 12.

[0026]

Step 2: As shown in Fig. 3(b), using the catalytic chemical vapor reaction apparatus 50, a surface of the epitaxial layer 12 is nitrided within an area located between the source electrode 15 and the gate electrode 14 and within an area located between the drain electrode 16 and the gate electrode 14, thereby forming the GaN surface-nitrided layer 20.

[0027]

Step 3: As shown in Fig. 3(c), the passivation film 17 of silicon nitride for instance is formed so as to cover the gate electrode 15 and the like. At this step, the field effective transistor 200 is completed.

[0028]

In the field effective transistor 200, since the GaN surface-nitrided layer 20 is formed immediately before forming the passivation film 17, a better interface between the passivation film 17 and the epitaxial layer 12 is obtained.

[0029]

Example 3

Fig. 4 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 3 which is generally denoted at 300. In Fig. 4, the same reference symbols as those used in Fig. 2 denote the same or corresponding portions. These manufacturing

steps include the following steps 1 through 5.

[0030]

Step 1: As shown in Fig. 4(a), first, on the substrate 11 of SiC or sapphire, the substrate 10 seating the GaN epitaxial layer 12 is prepared. Following this, a resist mask 19 is formed on the epitaxial layer 12 and an opening portion is formed in a source/drain region. Further, using the resist mask 19, a surface of the source/drain region is nitrided, whereby the GaN surface-nitrided layer 20 is formed.

[0031]

Step 2: As shown in Fig. 4(b), by a lift-off method using the resist mask 19 for instance, the source electrode 15 and the drain electrode 16 are formed. The source electrode 15 and the drain electrode 16 are formed on the GaN surface-nitrided layer 20.

[0032]

Step 3: As shown in Fig. 4(c), a resist mask 21 is formed on the epitaxial layer 12 and an opening portion is formed in a gate region. In addition, using the resist mask 21, a surface of the gate region is nitrided, whereby the GaN surface-nitrided layer 20 is formed.

[0033]

Step 4: As shown in Fig. 4(d), by a lift-off method using the resist mask 21 for instance, the gate electrode

14 is formed on the GaN surface-nitrided layer 20. Further, the remaining surface of the GaN epitaxial layer 12 is stabilized, whereby the GaN surface-nitrided layer 20 is formed.

[0034]

Step 5: As shown in Fig. 4(e), the passivation film 17 of silicon nitride for instance is formed so as to cover the entire surface. At this step, the field effective transistor 300 is completed.

[0035]

In the field effective transistor 300, since the surface of the GaN epitaxial layer 12 is stabilized and the gate electrode 14, the source electrode 15 and the drain electrode 16 are then formed immediately after forming the GaN surface-nitrided layer 20, the interface between the gate, the source and the drain electrodes 14, 15 and 16 and the GaN epitaxial layer 12 is in an excellent state. As a result, characteristics of the field effective transistor 300 improve.

[0036]

Example 4

Fig. 5 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 4 which is generally denoted at 400. In Fig. 5, the same reference symbols as those used in Fig. 2 denote

the same or corresponding portions. These manufacturing steps include the following steps 1 through 6.

[0037]

Step 1: As shown in Fig. 5(a), first, on the substrate 11 of SiC or sapphire, the substrate 10 seating the GaN epitaxial layer 12 is prepared. Further, a spacer layer 31 of silicon oxide is formed on the substrate 10.

[0038]

Step 2: As shown in Fig. 5(b), a resist mask 32 is formed on the spacer layer 31 and an opening portion is formed in a gate region. In addition, using the resist mask 32, a surface of the gate region is nitrided, whereby the GaN surface-nitrided layer 20 is formed.

[0039]

Step 3: As shown in Fig. 5(c), after removal of the resist mask 32, a gate electrode 34 is formed. The gate electrode 34 is patterned so as to have a T-shaped cross section. After the gate electrode 34 is thus formed, the spacer layer 31 is selectively removed using buffered hydrofluoric acid (BHF).

[0040]

Step 4: As shown in Fig. 5(d), a resist mask 33 is formed and an opening portion is formed in a source/drain region. Further, using the resist mask 33, a surface of the source/drain region is nitrided, whereby the GaN

surface-nitrided layer 20 is formed.

[0041]

Step 5: As shown in Fig. 5(e), by a lift-off method using the resist mask 33 for instance, the source electrode 15 and the drain electrode 16 are formed on the GaN surface-nitrided layer 20. Following this, the resist mask 33 is removed.

[0042]

Step 6: As shown in Fig. 5(f), the passivation film 17 of silicon nitride for instance is formed so as to cover the entire surface. At this step, the field effective transistor 400 is completed.

[0043]

In the field effective transistor 400 having the T-shaped gate 34, since the surface of the GaN epitaxial layer 12 is stabilized, characteristics of the field effective transistor 400 improve.

[0044]

Example 5

Fig. 6 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 5 which is generally denoted at 500. In Fig. 6, the same reference symbols as those used in Fig. 2 denote the same or corresponding portions. These manufacturing steps include the following steps 1 through 6.

[0045]

Step 1: As shown in Fig. 6(a), first, on the substrate 11 of SiC or sapphire, the substrate 10 seating the GaN epitaxial layer 12 is prepared. Following this, the substrate 10 is treated using the catalytic chemical vapor reaction apparatus 50, the GaN surface-nitrided layer 20 is formed on the surface of the GaN epitaxial layer 12. Further, using the same apparatus, a first passivation film 41 of silicon nitride for instance is formed on the GaN surface-nitrided layer 20. A spacer layer 42 of silicon nitride for instance is formed on the first passivation film 41.

[0046]

Step 2: As shown in Fig. 6(b), a resist mask 43 is formed on the spacer layer 42 and an opening portion is formed in a gate region. In addition, using the resist mask 43, a surface of the gate region is nitrided, whereby the GaN surface-nitrided layer 20 is formed.

[0047]

Step 3: As shown in Fig. 6(c), after removal of the resist mask 43, a gate electrode 44 is formed. The gate electrode 44 is patterned so as to have a T-shaped cross section.

[0048]

Step 4: As shown in Fig. 6(d), after the gate

electrode 44 is formed, the spacer layer 42 is selectively removed using buffered hydrofluoric acid (BHF).

[0049]

Step 5: As shown in Fig. 6(e), a resist mask 45 is formed and an opening portion is formed in a source/drain region. Further, using the resist mask 45, a surface of the source/drain region is nitrided, whereby the GaN surface-nitrided layer 20 is formed.

[0050]

Step 6: As shown in Fig. 6(f), by a lift-off method using the resist mask 45 for instance, the source electrode 15 and the drain electrode 16 are formed on the GaN surface-nitrided layer 20. Following this, the resist mask 45 is removed and a second passivation film 17 of silicon nitride for instance is formed so as to cover the entire surface. At this step, the field effective transistor 500 is completed.

[0051]

In the field effective transistor 500, since the T-shaped gate electrode 44 is formed after forming the GaN surface-nitrided layer 20 on the surface of the substrate 10 in advance, the GaN surface-nitrided layer 20 is formed uniformly even under the T-shaped gate electrode 44. Hence, even under the T-shaped gate electrode 44 in particular, the interface between the GaN epitaxial layer 12 and the

second passivation film 47 is in an excellent state.

[0052]

Example 6

Fig. 7 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 6 which is generally denoted at 600. In Fig. 7, the same reference symbols as those used in Fig. 2 denote the same or corresponding portions. These manufacturing steps include the following steps 1 through 4.

[0053]

Step 1: As shown in Fig. 7(a), first, on the substrate 11 of SiC or sapphire, the substrate 10 seating the GaN epitaxial layer 12 is prepared. Following this, the gate electrode 14 and the source and the drain electrodes 15 and 16 opposing the gate electrode are formed on the epitaxial layer 12.

[0054]

Step 2: As shown in Fig. 7(b), a thin insulation film 48 is formed so as to cover the entire surface. The insulation film 48 is of silicon nitride for example, and has film thickness of from about 10 angstroms to about 50 angstroms, and preferably, of about 20 angstroms. An aluminum film having about the same thickness may be formed instead of the insulation film 48.

[0055]

Step 3: As shown in Fig. 7(c), using the catalytic chemical vapor reaction apparatus 50, the GaN epitaxial layer 12 is nitrided and the GaN surface-nitrided layer 20 is formed. The GaN epitaxial layer 12 is nitrided by means of atom-state nitrogen transmitted by the insulation film 48 (or an aluminum film).

[0056]

Step 4: As shown in Fig. 7(d), the passivation film 17 of silicon nitride for instance is formed so as to cover the entire surface. The passivation film 17 and the insulation film 48 are both made of silicon nitride and integrated as one film. At this step, the field effective transistor 600 is completed.

[0057]

In the field effective transistor 600, the respective electrodes are formed first, the GaN epitaxial layer 12 is then coated with the thin insulation film 48, and the surface of the epitaxial layer 12 is nitrided through the insulation film 48. Hence, while the passivation film is being formed directly on the epitaxial layer 12, penetration of nitrogen (formation of nitrogen-induced voids) is prevented at the initial stage of formation of the passivation film which would otherwise occur, which in turn allows to maintain the interface between the epitaxial layer 12 and the passivation film 17 (insulation film 48)

in an excellent state.

[0058]

[EFFECT OF THE INVENTION]

As clearly described above, the surface stabilizing method and the method of manufacturing semiconductor device according to the present invention permit to nitride and accordingly stabilize a surface of a gallium nitride related semiconductor without damaging the surface.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1] Fig. 1 is a schematic drawing of the catalytic chemical vapor reaction apparatus which is used in the preferred embodiment of the present invention.

[Fig. 2] Fig. 2 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 1.

[Fig. 3] Fig. 3 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 2.

[Fig. 4] Fig. 4 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 3.

[Fig. 5] Fig. 5 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 4.

[Fig. 6] Fig. 6 is a cross sectional view which shows

steps of manufacturing a field effective transistor according to the example 5.

[Fig. 7] Fig. 7 is a cross sectional view which shows steps of manufacturing a field effective transistor according to the example 6.

[Explanation of Keys]

1 substrate stage

2 wafer

3 gas introduction portion

4 reactive gas

5 heat catalyst member

6 shutter

50 catalytic chemical vapor reaction apparatus

〔DOCUMENT NAME〕 DRAWINGS

Fig. 1

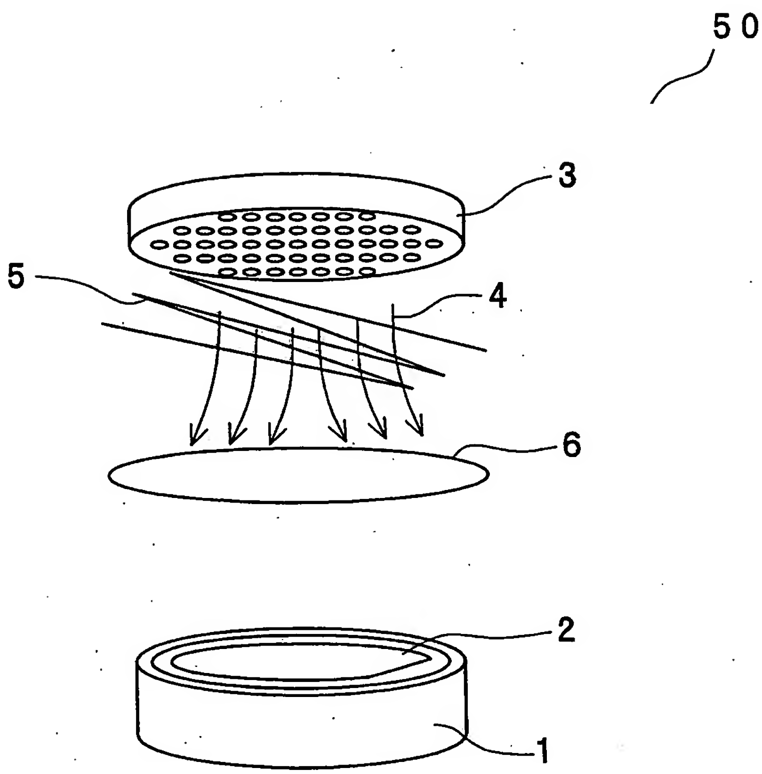

Fig. 2

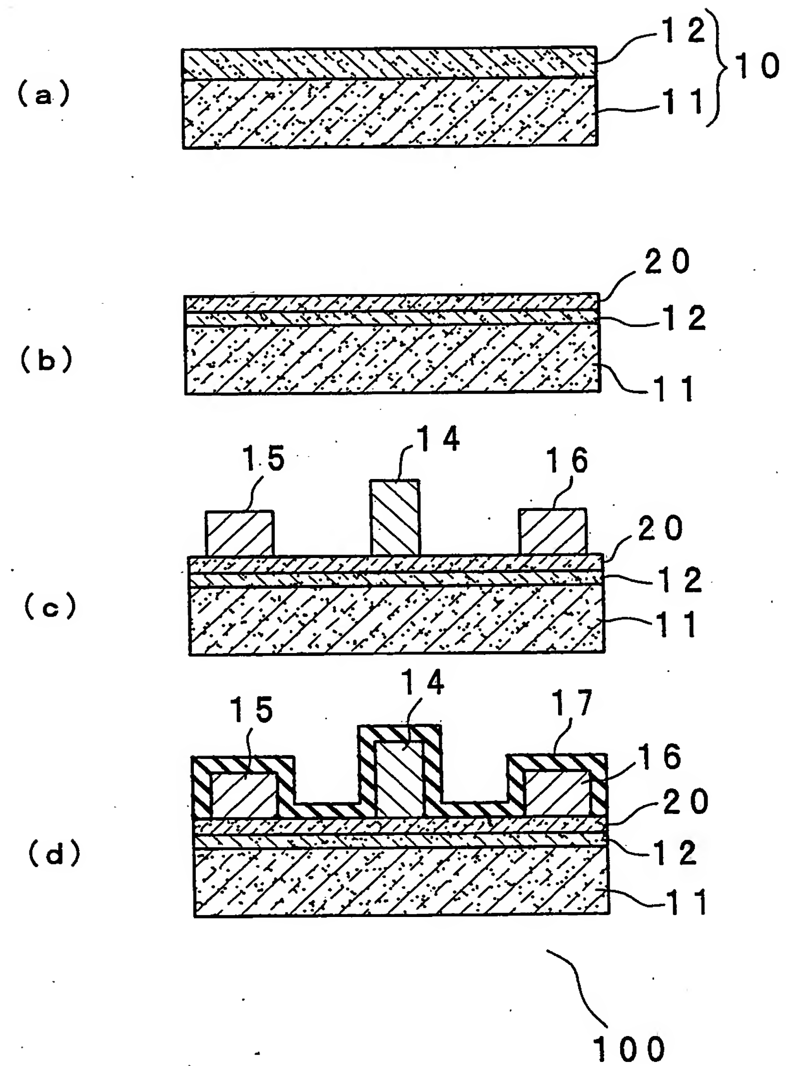

Fig. 3

(a)

(b)

(c)

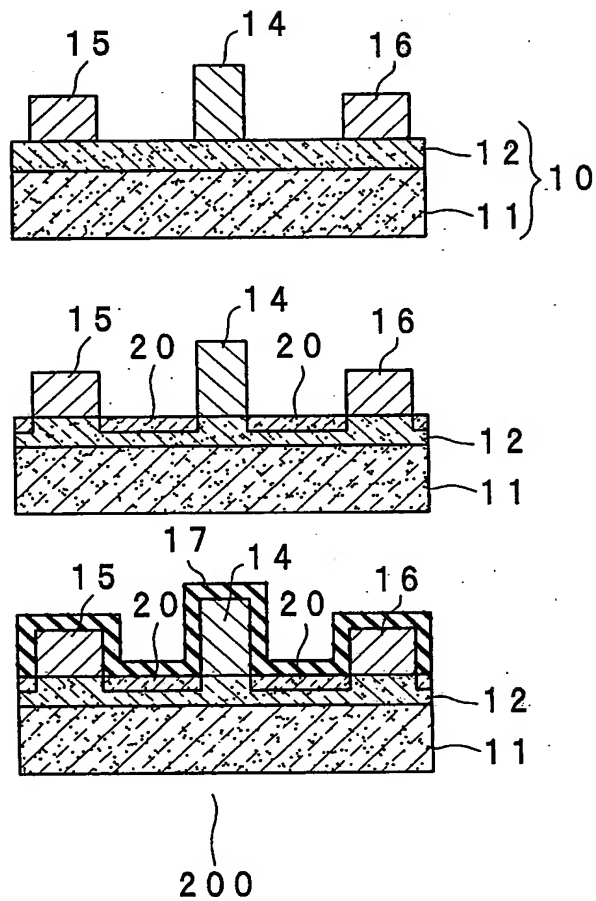

Fig. 4

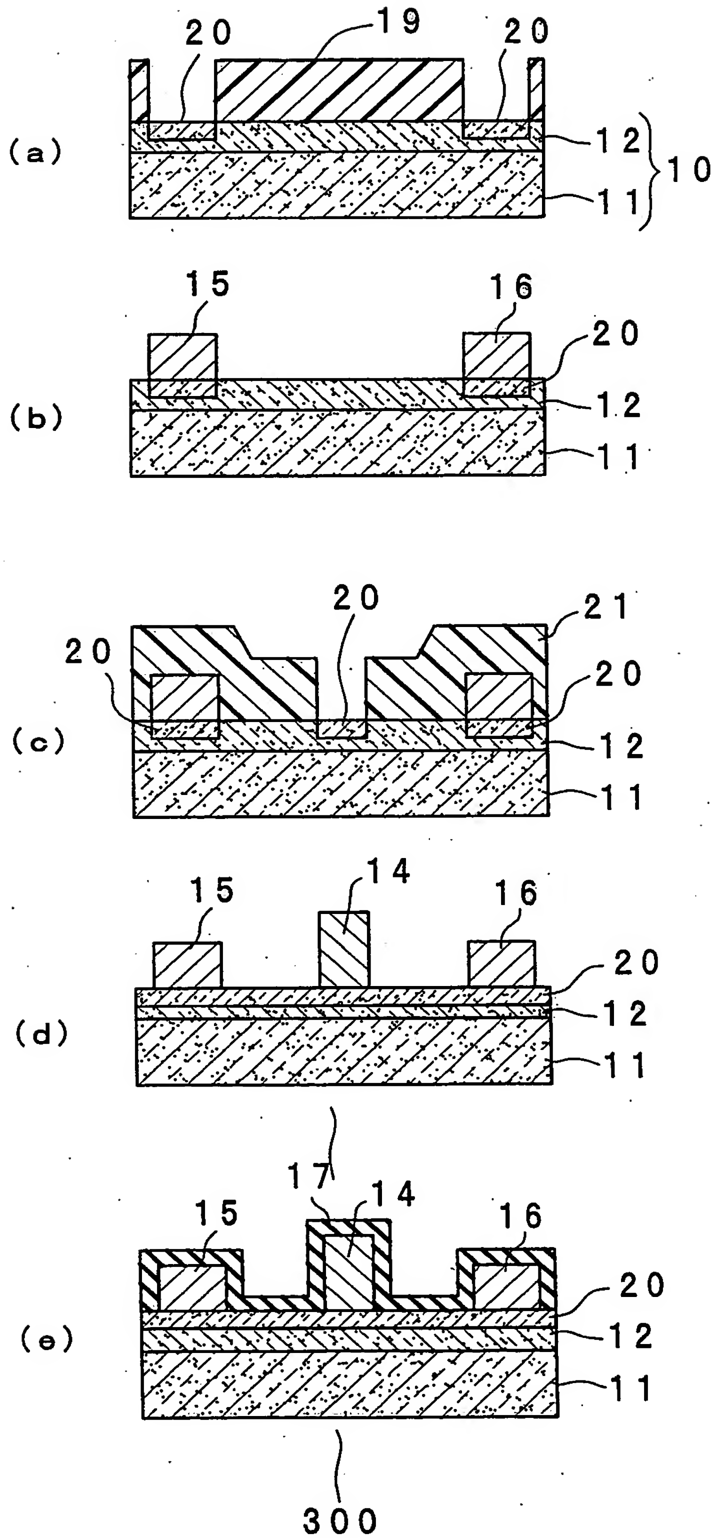
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Fig. 5

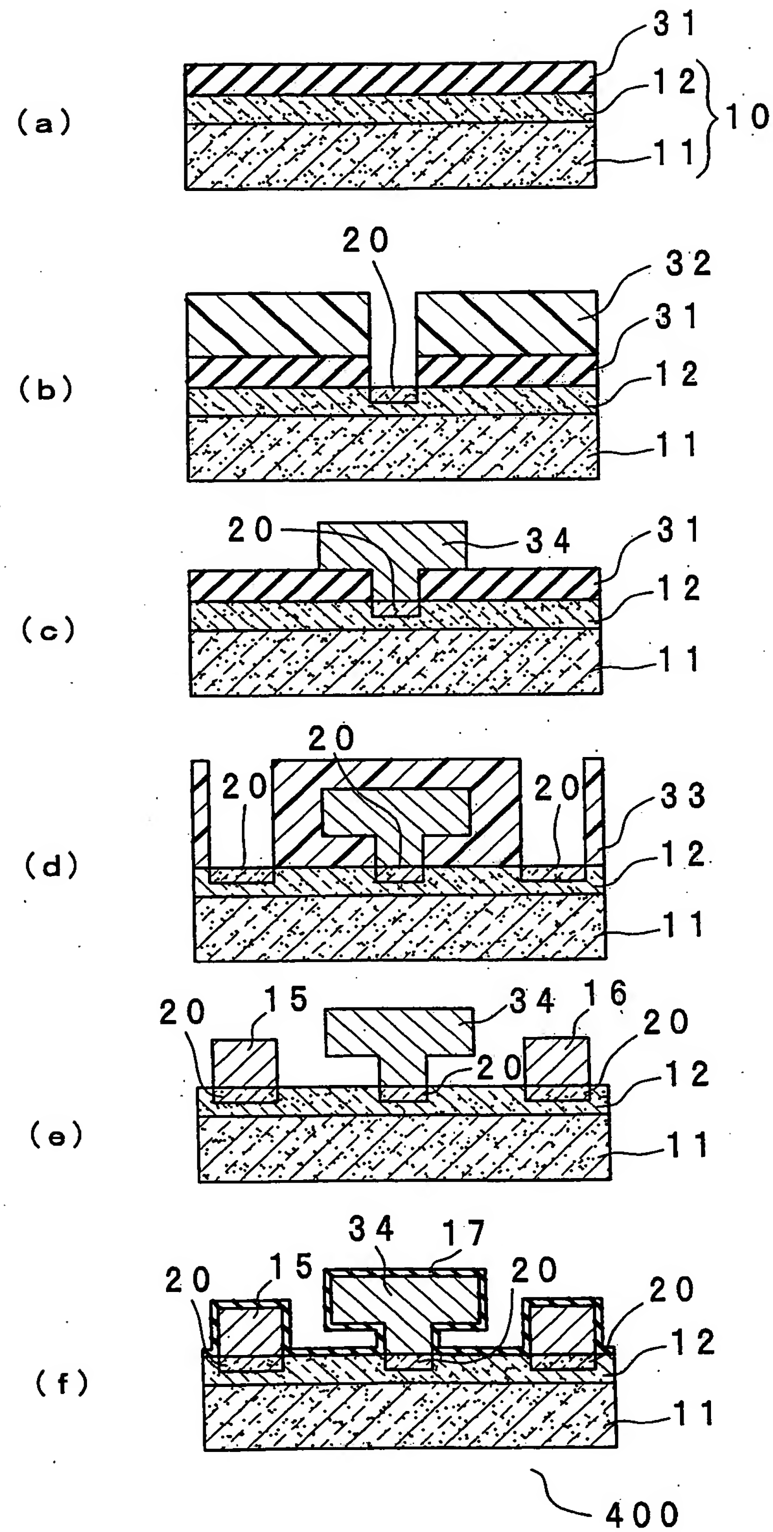
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Fig. 6

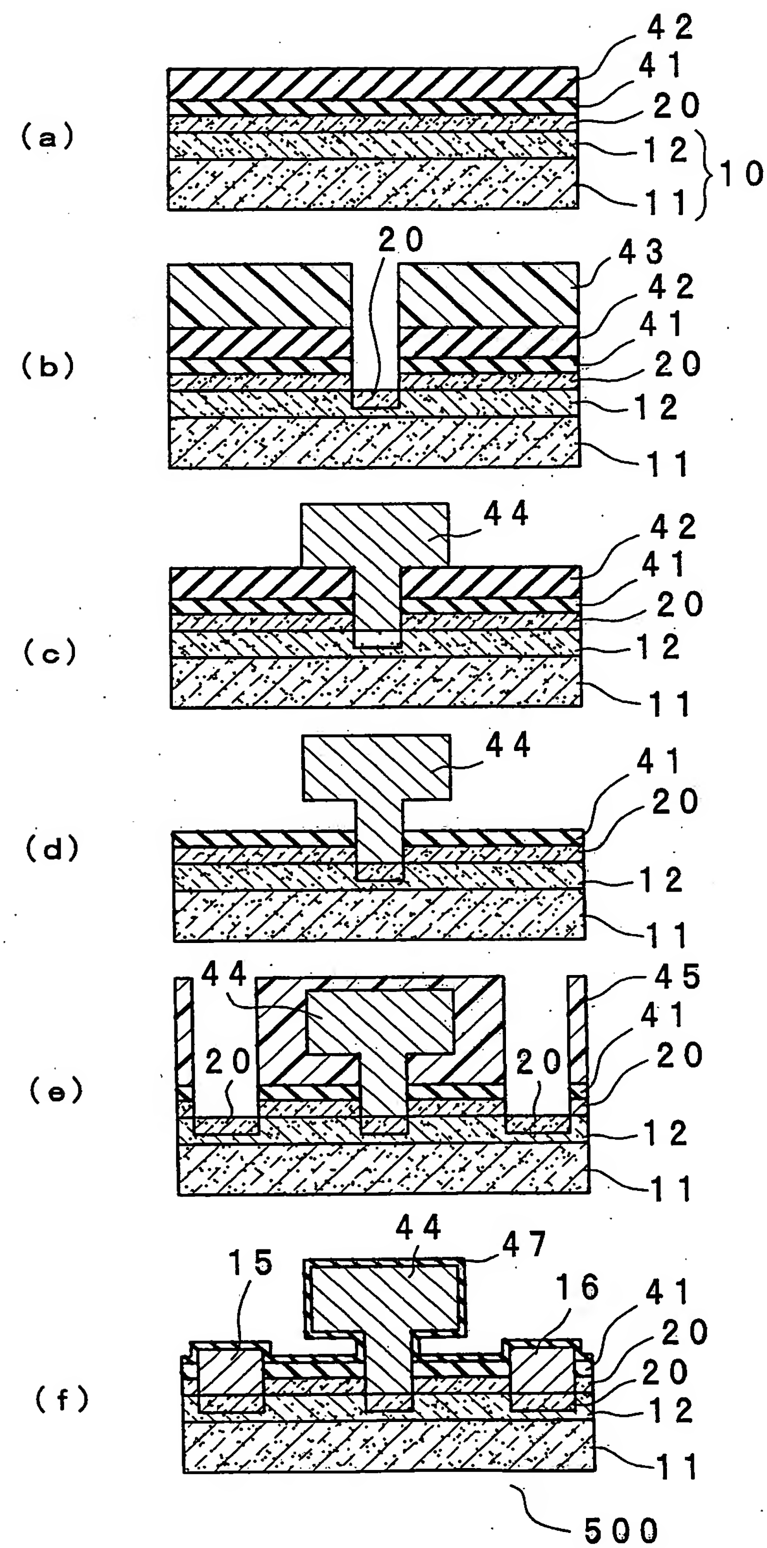
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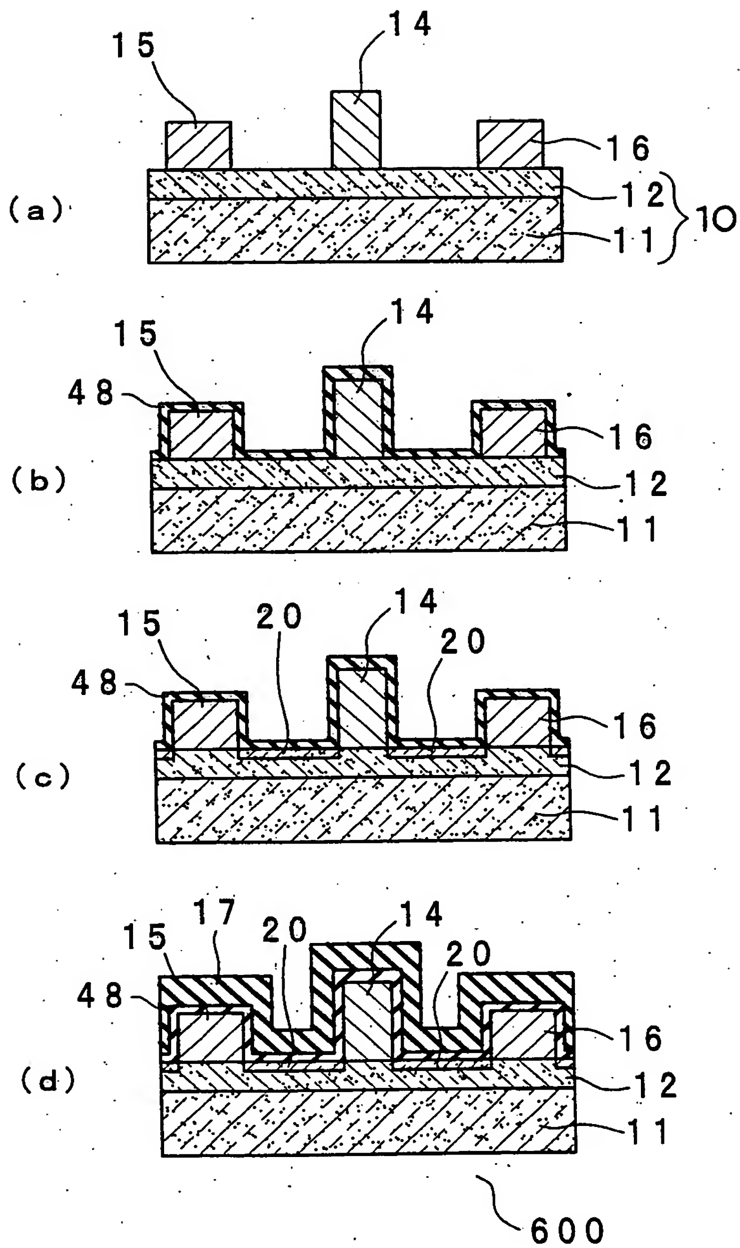
Fig. 7



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[DOCUMENT NAME] ABSTRACT

[SUMMARY]

[PROBLEM] Providing a surface stabilizing method which permits to stabilize a surface without damaging the surface.

[MEANS FOR SOLVING PROBLEM] A surface stabilizing method of stabilizing a surface of a gallium nitride related semiconductor substrate, using a catalytic chemical vapor reaction apparatus, including: arranging a gallium nitride related semiconductor substrate inside a catalytic chemical vapor reaction apparatus; introducing nitrogen-containing gas into the catalytic chemical vapor reaction apparatus; decomposing the nitrogen-containing gas by means of a catalytic reaction and forming atom-state nitrogen; and contacting the atom-state nitrogen with the semiconductor substrate and nitriding a surface of the semiconductor substrate.

[SELECTED DRAWING] Fig. 3

Applicant Record

Identification No.: 000006013

1. Date of Registration: August 24, 1990 (newly recorded)

Address: 2-3, Marunouchi 2-chome, Chiyoda-ku, TOKYO JAPAN

Name: Mitsubishi Denki Kabushiki Kaisha